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PRE-ECLIPSE OBSERVATIONS OF ϵ AURIGAE*

BY K. O. WRIGHT

ABSTRACT

The long-period binary star, ϵ Aurigae, will be in eclipse from 1955 to 1957. A brief discussion of the peculiarities of the system and of the explanations of the observed phenomena by Kuiper, Strömgren and Struve and by Kopal is given. High-dispersion spectrograms have been obtained at Victoria since 1946 and changes in the spectrum are illustrated. The ratio of emission to absorption at Hα appears to decrease as the eclipse approaches. Sharp lines to the red edge of the broad lines of ionized atoms have been visible since 1954, and similar features for neutral atoms appeared in July 1955. These lines are attributed to "chromospheric" effects in the atmosphere of the secondary star. In addition the broad lines in the spectrum of the primary star vary in width at irregular intervals, though the equivalent widths remain almost constant. The change in the shape of the lines may be due to turbulence in the atmosphere of the primary star.

THE star ϵ Aurigae has been observed quite intensively for more than a century and it seems probable that it will be studied even more thoroughly during the next two or three years when it will again be in eclipse. The system, which is almost certainly binary in character, has a period of 27.077 years, the longest that has been definitely established for other than a visual binary. At the eclipse of 1928–30 the light variations were studied photoelectrically by Huffer (1932) and others, and all the data concerning the star's variability in light were analysed by Miss Güssow (1936). From her study of the more than 13,000 observations that had been made since Fritsch discovered the star's variability in 1821, Miss Güssow found that the period is 9888 days and

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that mid-eclipse in 1929 was on J.D. 2,425,732. A plot of the photometric data at the time of that eclipse is shown in figure 1. Using her values of 714 days from beginning to end of the partial phase, D, and 330 days for the duration of totality, d, the corresponding data for the present eclipse are:

Beginning of partial phase	1955 June 5
Beginning of totality	1955 December 14
Mid-eclipse	1956 May 27
End of totality	1956 November 8
End of partial phase	1957 May 19

These dates may be in error by a few days. The elements of the orbit are somewhat uncertain because it has been found that there are irregular variations in the light of the star as large as 0.2 magnitude, which are superposed on the normal apparent visual magnitude of 3.4 and the visual magnitude during eclipse of 4.2. These irregularities are probably produced by an intrinsic variability of the primary star and, though they make the analysis more difficult and more uncertain, they make the study of the system even more interesting.

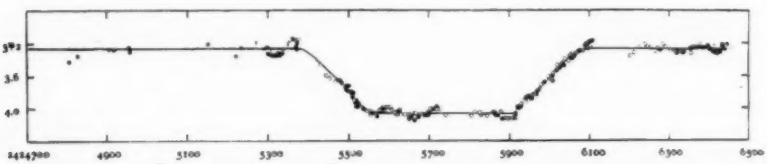

FIG. 1—The light curve of ϵ Aurigae from 1926 to 1931 showing the magnitudes computed from the geometrical elements (solid line) and the individual observations of Miss Güssow (filled circles) and of Stebbins and Huffer (open circles). Note the deviations from the computed curve. (Reproduced by *Sky and Telescope* from the *Publications of the Berlin-Babelsberg Observatory*)

The great interest in the present eclipse of ϵ Aurigae lies in the fact that it does not follow the usual pattern for a geometrical eclipse of one star by another. There are apparent contradictions both in the observed light variations and in the spectroscopic observations. The first peculiarity of the system is that the minimum is too deep for its observed duration. From the geometry of an eclipsing system one may show that

$$k \leqslant (D-d) / (D + d)$$

where k is the ratio of the radii of the two components. If we use the values given above for D and d, then $k \leqslant 0.38$ and $k^2 \leqslant 0.14$. The

inequalities occur because we are not certain of the inclination of the plane of the orbit. However k^2 is also proportional to the relative luminosities of the components and to their surface brightnesses. Since the loss of light during totality is 0.8 magnitude, or 52 per cent., then if the surface brightnesses were comparable, k should be about 0.72. In order to make the observations consistent, the surface brightness of the secondary would have to be only one-tenth that of the primary F-type star; it would then be a much cooler star than is known for any other system.

The spectroscopic observations obtained during eclipse are equally unusual (Frost et al. 1932). Some time before the partial phase began in 1928 (and also quite recently as we shall see later), the absorption lines, which are those of an F-type supergiant, became asymmetrical, with a sharp edge at the long wave-length side of the lines. These asymmetries increased as totality approached and reversed their positions during the partial phase following totality. High-dispersion spectrograms indicated that the asymmetries were probably produced by a sharp absorption line which appeared to the red of the normal line before eclipse and to the blue after eclipse, since two components of most lines could be measured on Mount Wilson spectrograms obtained by Adams and Sanford (1930) late in 1929 and early 1930. Somewhat similar sharp absorption features have been observed during the atmospheric eclipses of ζ Aurigae and 31 Cygni, and the displacements in all three stars may be due to the rotation of the secondary, eclipsing star. However, for ζ Aurigae and 31 Cygni the sharp, additional lines disappeared during totality, as would be expected during the total eclipse caused by an opaque star, whereas for ε Aurigae, the asymmetries could be observed well into totality and the additional component was probably present throughout the eclipse.

A further complication was that, except for the additional sharp absorption lines, the spectrum did not change during totality even though half of the light had been cut off. Struve and Elvey (1930) noted that the total absorptions of the lines may have increased slightly during eclipse, but the data were not sufficiently precise to be certain; such an effect could be produced by the additional absorption features noted above. Certainly the spectral type and the shape of the lines did not change markedly, though the dispersion used was too low to determine accurate line shapes. This result could be explained if the two stars were of the same spectral type and nearly equal in luminosity, but then double lines would appear when the stars were at the nodes, and for ε Aurigae no trace of the secondary spectrum, or even of a secondary

minimum has ever been observed. It could also be explained by an annular eclipse of a dark body. It should be pointed out that the amplitude of the radial-velocity variation, according to Ludendorff (1924), is only 15 km./sec. for the observed primary star and that secondary oscillations of nearly that amount were observed outside of eclipse between 1908 and 1911. However the normal places computed for the velocity-curve showed a fairly smooth mean variation with time that could be explained in terms of elliptical motion of two stars. If the two stars are nearly equal in mass, the velocity displacements should be nearly equal and the velocity difference between the two components should be more than 40 km./sec. at the time of maximum separation. A separation of this amount should be observable if any lines of the secondary component are present in the spectrum.

A diminution of light during eclipse by one-half could be produced if the primary star were much larger than the secondary, in which case the eclipse would be annular, but the shape of the light-curve for ϵ Aurigae indicates that the secondary star is larger than the primary.

All the observations were studied in detail by astronomers at the Yerkes Observatory and, in a detailed discussion of the problem, Kuiper, Struve and Strömgren (1937) came to the conclusion that the known data could be explained if the system consisted of a supergiant primary star, which produces the observed spectrum, and an even larger semi-transparent star with a temperature of about 1200° K. which eclipses the primary star. The inclination of the orbit is about 70° and therefore at eclipse the light of the primary star passes through only the outer layers of the secondary star. Detailed calculations by Strömgren showed that if there were excess radiation in the far ultra-violet region of the F-type primary star, the outer layers of the companion could be ionized by electrons in the atmosphere of the secondary star to produce the observed loss of light at eclipse.

Two recent papers by Kopal (1954, 1955) have criticized this model. If the secondary star had a low temperature, there would be an excess of radiation in the infra-red, whereas observations by Fellgett (1951) and by Kuiper (1953) with lead sulphide cells out to 30,000 A. show little or no excess radiation; further, a red star of the required luminosity should show molecular absorption, and this has not been observed. Kopal also notes that in order to avoid Rayleigh scattering by hydrogen atoms inside the ionized layer of the secondary star (which would produce an effect having a large variation with wave-length) the hydrogen abundance would need to be low, and strong lines of neutral atoms such as calcium would be much stronger than observed. Electron

scattering would also produce polarization effects, but Hall (1953) found that the polarization of ε Aurigae was only 2.2 per cent., an amount that can be accounted for by interstellar dust. These remarks, together with the cautious statements of Strömgren in his original discussion of the problem, indicate that the puzzle of the secondary component of ε Aurigae cannot be considered solved.

Kopal (1955) has extended a suggestion of Schoenberg and Jung (1938) that solid particles might produce the effect observed during the eclipse. He suggests that there may be a semi-transparent, flat ring surrounding the secondary star and inclined to the orbital plane of the system. Kopal notes that such a flat ring could be stable and semi-transparent and that it could produce a flat minimum during eclipse. The total mass required for particles having diameters between 10 and 100μ would be only 10^{27} gm., which is less than the mass of the earth. Such a ring requires no excess ultra-violet radiation or abnormally low abundance hydrogen in the primary star. The secondary star in such a case could be quite small as the edge of the ring would define the eclipse. However such a ring would not eliminate the need for a gas cloud or extensive atmosphere surrounding the secondary star since the sharp features associated with the asymmetries of the lines before and after eclipse seem to require a very extensive tenuous atmosphere of a secondary star rotating with a speed of about 50 km./sec. The need for both solid particles and a gaseous atmosphere about the secondary star, both of which are very extensive, makes this model appear somewhat artificial, and indicates that further study of the system is desirable.

A high-dispersion study of the spectrum of ε Aurigae was begun at the Dominion Astrophysical Observatory in 1946 and first results (Wright and van Dien, 1949), based on curve-of-growth studies, confirmed the analysis of Struve and Elvey (1934) that there are large turbulent motions in the atmosphere, and indicated the possible presence of stratification in the atmosphere of the primary component.

Observations have been continued and the star has now been observed with high dispersion on 55 nights, 17 of which have been in 1955. The present note is intended to describe and illustrate a few of the interesting features of the pre-eclipse spectra of ε Aurigae. A more detailed discussion of the data is planned when observations during the eclipse have been obtained.

Figure 2 shows spectra in the region of the red Hα line of hydrogen, which is the only feature that shows emission throughout the cycle. The first two spectra were shown and compared with the Hα region

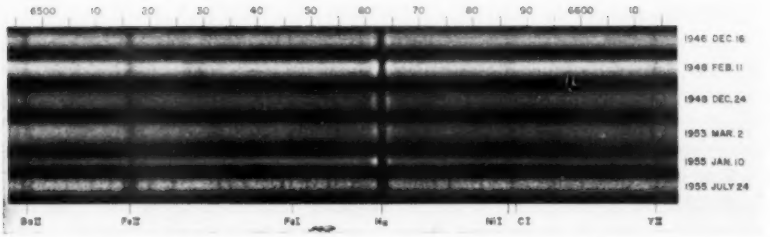

FIG. 2—Spectra of ε Aurigae in the region of Hα. Emission features appear at each side of the absorption Hα line on all spectra but are much more prominent before the approach of eclipse. The sharp lines not identified are produced by terrestrial water vapour.

in α Persei in a previous publication (Wright and van Dien, 1949). There it was seen that the central core of Hα in the spectrum of α Persei is about 2 A. wide and on intensity tracings the wings extend about 20 A. on either side of the centre. In the 1946 spectrum of ε Aurigae, the central core was partially filled in by emission, but beyond the emission the normal wings of the line extended more than 10 A.

The spectra of Hα in figure 2 all show emission on either side of the central absorption, and though the central absorption varies considerably in intensity its width between the two emission edges remains nearly constant. The apparent step between the absorption core and the short wave-length emission edge on the plate of 1946 December 16 is real, as two plates taken in succession on that night show the same effect. The central absorption core on the plates taken in 1955 is appreciably deeper than that on the earlier plates and the intensity of the emission edges seems to be decreasing; a weak plate taken on May 9 confirms this observation. A note by McLaughlin (1935) discussing the variable Hα emission in the spectrum of ε Aurigae indicates that on 1929 October 14, during totality, there was an absorption core and "probably narrow emission borders", similar to the 1955 spectra shown here. However on one-prism spectra obtained on 1935 January 22 and March 15, nothing could be seen at Hα; the emission and absorption features apparently balanced each other. This observation may be related to the apparent step in our 1946 spectra but unfortunately, so far as is known, no spectra of Hα were obtained between 1935 and 1946.

Changes in the spectrum of ε Aurigae in the regions λλ4214–4304 and λλ4323–4408 between 1946 and 1955 are shown in figures 3 and 4. These plates show two different types of change in the shapes of the lines.

First, and of great interest in connection with the forthcoming

eclipse, is the appearance of sharp absorption features at the red edge of many of the normally broad lines of the F-type primary spectrum. They are shown very clearly on the spectrum of 1955 July 22 where lines of the following atoms have been identified: ionized strontium, iron, scandium, titanium and yttrium, and neutral calcium, iron, hydrogen and chromium. All of these lines except hydrogen arise from levels of fairly low excitation (less than two volts) and, in general, the lines that do not show absorption edges arise from levels of higher excitation. The great difference in appearance between the spectrum of May 13 and that of July 22 indicates that at the later date the light of the primary star was passing through a layer of considerably greater density (or much greater extent) than it was in May; this observation agrees with the prediction that the photometric eclipse would begin early in June. However the sharp redward components of the lines of Sc II, λ4246 and of Ti II, λλ4294, 4337, 4395, 4444 and 4468 have been visible on all of the Victoria plates obtained in 1955 and some of the sharp components can be detected on plates taken early in 1954. Struve (1953) states that on plates taken at the Mount Wilson Observatory lines that were symmetrical in 1950 began to show asymmetries as early as 1951.

The second major change in the shapes of the lines in the spectrum of ε Aurigae is also quite startling when a series of similar spectra are compared, as in figures 3 and 4. Sometimes the lines are broad and fairly shallow; sometimes they are relatively sharp and appreciably deeper, though they are never comparable in sharpness to the lines in the spectrum of, for example, Procyon. The equivalent widths, measured on

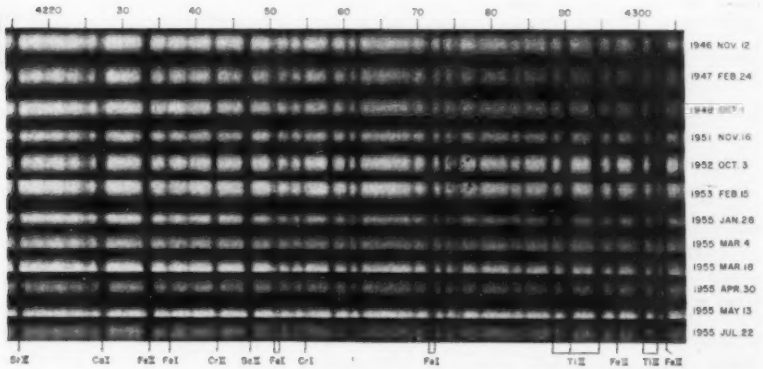

FIG. 3—Spectra of ε Aurigae in the region λλ4214–4306. Note the sharp absorption features at the long wave-length edge of many of the lines in the spectra of later date, and also the change in shape of the lines as shown by the Fe I doublet at λ4250.

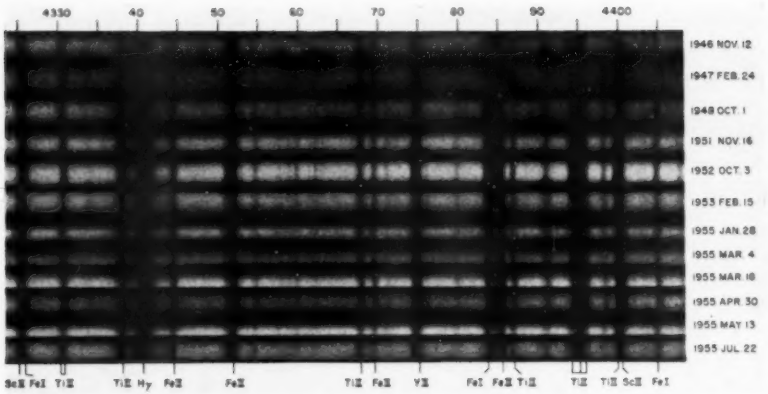

FIG. 4—Spectra of ϵ Aurigae in the region λλ4323–4408. Note the sharp absorption features at the long wave-length edge of many of the lines in the spectra of later date, and also the change in shape of the lines as shown by the almost complete disappearance of the weak lines between λ4360 and λ4390 on 1948 October 1, 1955 January 28 and 1955 July 22.

intensity tracings, do not change much, but there may be small, real variations. Although the changes in line shape can be seen best for lines of moderate strength, it is probable that all lines are affected. For illustrative purposes the Fe I doublet at λ4250 (figure 3) separated by 0.7 A. shows the changes most strikingly. The two lines are well separated on 1946 November 12, 1951 November 16 and 1952 October 3; they cannot be separated at all on 1948 October 1, 1955 January 28 or 1955 May 13. The other spectra show separations intermediate between these extremes. The changes in line shapes seem to have occurred at irregular intervals and no periodicity has yet been found. Spectra obtained on successive nights are quite similar but the lines appear to be a little sharper on 1946 November 12 than they were two nights earlier.

Since these changes in the widths of the lines have been observed since 1946, when the primary star was in front of its companion, it seems probable that they are associated with the primary which is itself a supergiant star. The changes may well be related to the known variations in light and in radial velocity. It is by no means certain that the two latter effects are correlated, although it has been suggested that they sometimes vary at intervals of 100 to 150 days.

The changing shapes of the lines may be associated with large-scale turbulent motions in the atmosphere of the supergiant star. If discrete

clouds of matter were ejected from the star, they might be detected by their radial-velocity differences. Indeed, such an interpretation has been given to the sharp, displaced components of the Ca II lines observed during the atmospheric eclipse of 31 Cygni. If the disturbance was of large size, or if several clouds were ejected almost simultaneously, the material might extend over a large arc. Then there would be a large range in the radial velocities and the spectrum lines would appear broader than usual. Such a phenomenon would be additional evidence for the presence of turbulent, or at least large-scale, motions in stellar atmospheres.

The Doppler motions that affect the profiles of the lines in a stellar spectrum may occur in either large or small elements, relative to the effective path-length of the radiation passing through the atmosphere. Since the changes in line shapes observed for ε Aurigae do not affect the equivalent widths markedly, it would appear that the masses of gas producing the lines are large relative to the whole atmosphere. Thus there may be many such disturbances continuously contributing to the shape of each line. If this explanation is correct, the questions yet to be solved are why the disturbances occur at irregular intervals, and why the shapes of the lines are so symmetrical.

These observations may be related to the variations observed (Struve, 1932) in the spectrum of 17 Leporis, the star with the largest known turbulent velocities as measured from curve-of-growth data. In 17 Leporis, the lines are sometimes fairly sharp and deep; at other times they are broad and shallow and show evidence for two components. The characterististics of the spectrum are like those of a shell star rather than of a spectroscopic binary; the phenomena may last for weeks, and no definite periodicity has been found.

There are very few examples of stellar spectra that show real changes in the shapes of the spectrum lines. The spectra of two stars that were formerly considered to have broad lines at certain phases have been shown to exhibit double lines when observed with the highest dispersion. For the β Cephei star, BW Vulpeculae, Struve (1954) showed conclusively that the broad-line phase at the still-stand was only apparent and that two component lines, separated in radial velocity by 40 to 120 km./sec., were actually present in the spectrum at that time. For the type II Cepheid variable, W Virginis, Abt and Sanford observed double lines over one-quarter of the period. Abt (1954) explained these observations in terms of numerous cloud-like condensations of such size and number as to make collisions improbable as they rose and fell in the atmosphere.

A similar doubling of the lines in the spectrum of ε Aurigae seems

rather unlikely, or at least would be very difficult to detect since the lines are quite broad at all times, and since high dispersion has already been used in the present study. However, pulsation phenomena have been considered in connection with many types of stellar variation, and it is not impossible that the present observations may be explained in that way also.

Dominion Astrophysical Observatory,
Victoria, B.C.
August 1955.

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THE REGINA ASTRONOMICAL SOCIETY, JUNE 1955

By John Hodges

In June 1910, a group of Regina citizens interested in astronomy were observing from an observatory built on the roof of the only collegiate Regina had at that time. They had seen Halley's comet come and go. The interest shown by this group warranted the purchase of a telescope, and Justice J. T. Brown bought a four-inch Brashear refractor for what became the Regina Astronomical Society.

Unfortunately, the men who were the backbone of the new organization were soon scattered by the events of the First World War, and later Dr. A. J. Pyke, the guiding light of the group, was transferred to the University of Saskatchewan at Saskatoon. There was no one to fill his place, and the little Society ceased to function.

Very little is known about the history of the Society in the twenties. The objective lens was stolen from the Brashear, whether in jest or in earnest was never established. After the uproar had subsided, everyone forgot about the Society. It just does not appear to have existed at that time.

The Brashear telescope was removed in the early thirties from the Central Collegiate roof and Mr. H. S. McClung purchased another lens for it. Fortunately for us to-day, the telescope received little use and its condition remained excellent. Another war brought everything to a standstill until 1945.

For some time A. G. Ingalls of the *Scientific American* had been promoting the hobby of amateur telescope building. In this he was assisted by the articles and the now-famous drawings of R. W. Porter. By 1945 the hobby was well established in Regina. A handful of local enthusiasts independently had built or were planning to build telescopes, and this group became acquainted with the present writer who realized that this was the means of reviving the society. Meetings were held in members' homes, often in basement workshops. The group agreed that there must be many more people interested in things astronomical, and made ambitious plans to gather them into the fold. Out of a total of only twelve members, eight, with a lot of nerve, decided to ask for exhibit space in the provincial exhibition of 1951. Equipped with films, a public address system, large wall murals and telescopes, along with a Foucault pendulum, the exhibit stole the show. The Society grew to 35 members.

Naturally we hoped to have a housing for the telescope, where it could be preserved from vandalism. Prior to the exhibit, models were built of various styles of observatory that could be made from an

emergency shelter. These models drew considerable attention at the fair, but our hopes of having such an emergency shelter donated were not fulfilled immediately.

Fortunately for us, the Perseid meteor shower followed the exhibit and a local radio station gave a broadcast on the observing technique while operations were being carried on. This publicity along with the press account of our activities brought attention to our efforts, and by the end of October we had been donated an emergency shelter.

We had long before selected what could be the ideal site for our observatory. We discussed it with Dr. W. A. Riddell, Dean of Regina College, and through his efforts a "tarmac" area to the south of the college, originally a fenced parade-square, was leased to the Society. The shelter was moved onto this site before winter set in. The year proved a very fruitful one, especially when we learned that our shower observations had been well received by Dr. Peter M. Millman at the Dominion Observatory, Ottawa.

As soon as spring arrived in 1952 the members made the shelter into a proper lecture room, library and storage place, fit for use the year round. The Society had decided to build a separate building for an observatory, although there seemed little chance of starting it immediately owing to lack of funds. However, the beg, borrow and scrounge system was put into effect with great success. Before winter again put a stop to operations, the cement base for the telescope was poured and the entire floor finished.

Full-scale patterns for the twelve-gore dome were built during the winter and so spring found several projects under way—the walls and roof of the observatory, the track and main twelve-sided girder of the dome, and a platform on which to build the dome. By the middle of summer the aluminium arrived and everyone, by necessity, became tinsmiths. A contribution had made the purchase of the aluminium sheeting possible. There was excitement the evening the dome was placed in position and turned with ease. However, the shutters had not been started, and I advise all to approach this type of mechanism humbly. It is a very tricky project and definitely must be built right to be satisfactory. It was decided to build the shutters and frame during the winter. Our plan called for this to be a unit, fully operable before installation in the dome. In April 1954, the unit had met our approval and was transported to the observatory site.

While the dome was being fabricated on a special platform that we called the "work-bench", and eleven of the twelve gores had been completed, a storm struck the area. The wind reached sixty miles an hour and it was accompanied by medium-sized hail-stones. A close

inspection showed that beyond slight indentations on one gore the dome had suffered no damage.

To assist those who plan to build an observatory I should mention that for a dome 12 feet in diameter we used twelve gores, thirty-seven inches across their bases, joined together by a double-turned standing seam. The material, which has proved satisfactory, is 20-gauge half-hard aluminium sheets—supplied in 4 × 12 foot sheets. Seven sheets were sufficient for the twelve gores and for material to cover the two shutters. As a rule, observatory domes require an opening no less than one quarter the diameter of the completed dome. Thus we needed a 3-foot opening and our plans called for horizontally-opening shutters as found in the conventional dome.

In the fall, all that remained was to finish the interiors of both buildings, which would take money. Prior to this the project had required skills, all of which were possessed or quickly acquired by club members. We lacked funds because our society fees were as low as possible so that all could afford to belong. However, the members themselves loyally raised the funds to finish the two buildings.

We planned for an official opening in June of 1955, and now the weather seriously interfered with progress. Saskatchewan will long remember the floods during the spring of this year. By working every available moment we completed the project a few hours before the official opening June 4, 1955.

Dr. Peter M. Millman had been asked to officiate at the opening of the observatory. There was a flurry of excitement when our invitation was accepted for the date chosen. June third was cloudy and wet for Dr. Millman's arrival, but the forecast was optimistic. The schedule was a crowded one: an interview by the press, a radio interview, an appearance on TV and a reception. Saturday was bright but comfortably cool and the outdoor programme went over without a hitch. As president of the Society, I had the pleasure of introducing Dr. Riddell, who had assisted us greatly in our project. Dr. Millman followed Dr. Riddell, and bestowed great praise on the group who had worked so effectively in producing a very creditable observatory. He then told us about the part enthusiastic amateurs could play in the International Geophysical Year of 1957–58. He then turned and opened the door of the Observatory and, cutting the ribbon, declared the Observatory officially open. In doing so, he climaxed the events of four years of planning and building. The cost had been less than $500.

Following the opening ceremonies, the Society held a dinner, which is to be an annual affair from now on, and a charter member, the Hon. Chief Justice J. T. Brown, was introduced by Mr. R. G. Harper, toast-

FIG. 1—The Regina Observatory. The clubroom on the left contains the library and instructional equipment along with furnishings to make it a comfortable operations centre. The 2.7-inch Dolland refractor and the 10-inch reflector are on permanent mountings in front of the buildings. The observatory houses the 4-inch Brashear refractor.

master. Chief Justice Brown told how parts of the telescope had been scattered—some as far as Winnipeg, the base itself having been relocated under three tons of coal in a Regina hospital.

Dr. Millman spoke that evening from the stage of the new auditorium in the recently-opened Provincial Museum. The address, "Domes Against the Sky", was a fascinating trip to many historic and modern observatories in North America. It is necessary to see the colour shots Dr. Millman has taken to appreciate their beauty. His talk was followed by the film, "The Story of Palomar".

Sunday was Open House and the Society entertained over 400 people. Everyone was happy and tired when the shelters were finally closed Sunday evening. It had been a memorable week-end.

With a steadily growing membership, over one hundred at the date of writing, the members of the Regina Astronomical Society can reflect with justifiable pride on the immense progress of their Society since that little group of observers first met on a roof top in June 1910. They can look forward to active enjoyment of the fruits of their past labours, and to a real contribution in amateur astronomy.

RADIO BRIGHTNESS DISTRIBUTION OF THE SUN AT A WAVE-LENGTH OF 10.7 CENTIMETRES JUNE 30, 1954

By A. E. Covington, W. J. Medd, Mrs. G. A. Harvey, N. W. Broten

Abstract

A partial eclipse of the sun was observed on June 30, 1954 at the Radio Observatory of the National Research Council in Ottawa. During the eclipse, a record of the varying ten-centimetre solar radiation from a 2-degree region containing the sun and moon was obtained with a paraboloid reflector ten feet in diameter. After the eclipse, when the sun drifted through the receiving pattern of a 150-foot waveguide array, solar radio emission was obtained in north-south strips approximately 1/8-degree wide. These observations have been interpreted in terms of a disk with a radius 1.14 times that of the photosphere and with the equatorial regions brighter than the polar regions. Equivalent temperature at the centre of the radio disk is about 33,000°K.

The existence of radio waves originating from the sun has been known for a little more than a decade and has both supplemented and extended our physical knowledge of the solar atmosphere. Many of the early observations were taken with instruments of such low resolving power that no angular discrimination was made between points on the solar disk and in consequence, the total emission from the disk was received. Only recently, with the construction of large antennas, has it been possible to isolate regions on the disk with an accuracy of a few minutes of arc. Eclipse observations offer a means whereby sources of radio waves may be located with great accuracy although an instrument of low resolving power is used. The positioning of an emitting source is limited to a single parameter since the source may lie anywhere on the circle representing the moon's edge. This ambiguity makes the interpretation of eclipse records difficult. The limiting accuracy with which a point may be located anywhere upon a circle in a radial direction is dependent upon the diffraction of the radio waves by the moon's limb. At a wave-length of 10.7 centimetres, this amounts to about 3.5 seconds of arc, an equivalent resolving power which can only be attained by an antenna of aperture of 4 miles. Unfortunately the full use of this equivalent resolving power is usually limited by uncertainties in the record introduced by the residual receiver noise.

The radio observations of the partial solar eclipse which occurred in Ottawa on June 30, 1954 were taken at the Radio Observatory of the National Research Council. The observations were started before the

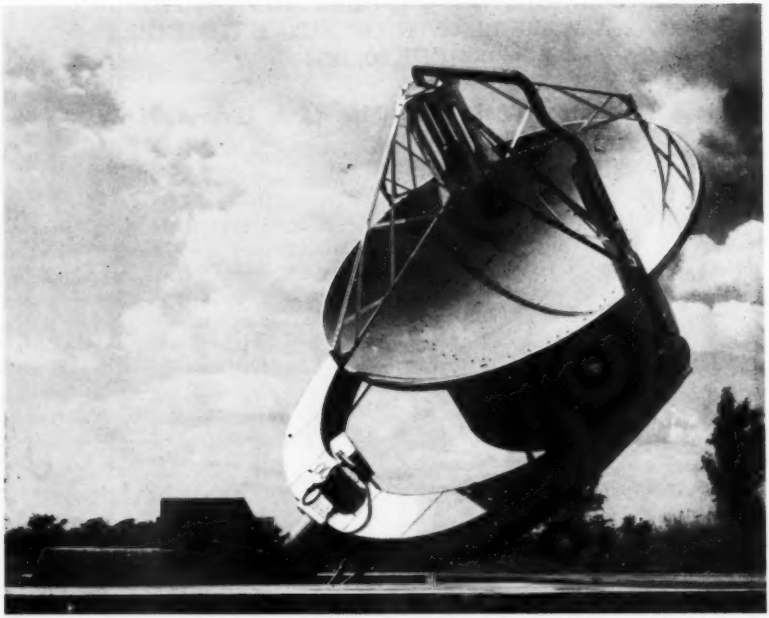

FIG. 1—10.7-centimetre radio telescope at National Research Council, Ottawa, Canada—10-foot diameter paraboloid.

first contact and continued until the eclipse was well over. As the moon covered various portions of the sun's disk the total solar radio output was detected and recorded. Two such records, or eclipse curves, were obtained: one with the recently installed 10-foot parabolic reflector (figure 1), which has a receiving pattern of 2.5 degrees to the half-power points, and the other with the 4-foot parabolic reflector, which has a receiving pattern of 7 degrees to the half-power points. Both antennas were motor-driven so that the acceptance cone remained on

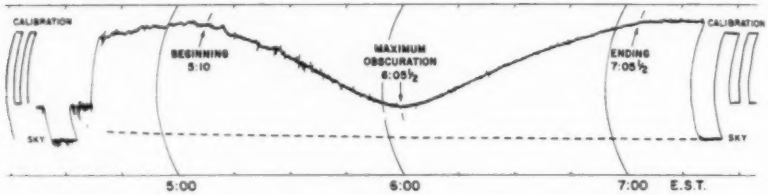

FIG. 2—Eclipse curve, June 30, 1954, obtained with 10-foot paraboloid.

the region containing the sun and moon. Since the larger instrument receives more solar energy than the smaller one, the eclipse record so obtained (figure 2) will have greater relative accuracy and consequently was used in the subsequent analysis. The absolute value of the solar flux was obtained with the smaller antenna since its various parameters have been well investigated.

Since the eclipse commenced shortly after sunrise and lasted until an elevation of 30 degrees had been reached, a correction for the atmospheric absorption and the emission from the sky and earth had to be determined. Patrol observations were taken on the days both preceding and following the eclipse. On each day, after the sun had traversed the path of interest, the antenna was driven back over the same path in order to determine the emission from the sky and earth. In figure 2 this is shown as a dashed line. If the assumption is made that the sun is a signal generator of constant output, then an appropriate correction factor may be found for each angle of elevation and can be used to restore the observed low angle solar emission to the value observed at a higher elevation. Examination of several days' records, including the day of the eclipse, showed some fluctuations just after sunrise. Since most of these were of a non-repeatable nature, it was thought that they were probably of atmospheric origin and not related to any pattern caused by the interference of direct solar rays and a reflection from the ground. This unexplainable roughness of the record during the early part of the eclipse introduced considerable error in comparison to the subsequent period, so that it was decided to use only the smoothest section of the record—a section commencing before maximum obscuration and extending to beyond last contact. For this period of interest the atmospheric and earth corrections are very small, varying from 2 per cent. to 0.25 per cent. In addition, during the first part of the eclipse there were a few minutes of circuit instability which cured itself before the time of maximum obscuration. This appears as sharp lines across the trace but otherwise does not spoil the record. The relative gain of the radiometer was measured by reference to the noise emitted by a fluorescent lamp both before and after the eclipse. These measurements showed that during the three-hour period of observations the gain of the radiometer had changed by only 1 per cent.

The second set of radio observations was taken about five hours after the eclipse when the sun was near the zenith and passing through the narrow fan-shaped receiving pattern of the long array (figure 3). This antenna is 150 feet long and has a receiving pattern approximately 1/8-degree east-west and 20 degrees north-south. The output of the

FIG. 3—10.7-centimetre radio telescope at National Research Council, Ottawa, Canada—150-foot slotted waveguide array.

receiver when the sun drifts through the narrow section of the antenna pattern has been called a drift curve (figure 4) and its analysis gives some knowledge of the angular distribution of the radio emission from the solar surface (Covington and Broten, 1954). Four drift curves which differ from each other only by amounts that may be ascribed to the receiver fluctuations were taken with this instrument. After normalizing each with respect to the 4-foot reflector, the average of the four curves was obtained for use in the subsequent analysis. This average curve is very symmetrical, the area of one half agreeing with that of the other to one part in 250, and is evidence that the radio sun is axially symmetrical. The patrol days before and after the day of the eclipse showed similar drift curves, from which it is concluded that there were no radio emissive regions present on the visible hemisphere during this period. The two halves of the average drift curve were again averaged to give the drift curve readings that were analysed. It is interesting to note that this curve is very similar to that of the quiet sun lower envelope found in 1952 (Covington and Broten, 1954).

Radius of the Radio Sun

The radius of the radio sun is an important characteristic and is perhaps best determined, to a first approximation, from the eclipse curve rather than from the drift curve. The shadow of the moon's edge is very sharp in comparison with the fan-shaped antenna pattern of the long array, so that the edge of the radio disk is located by the transition

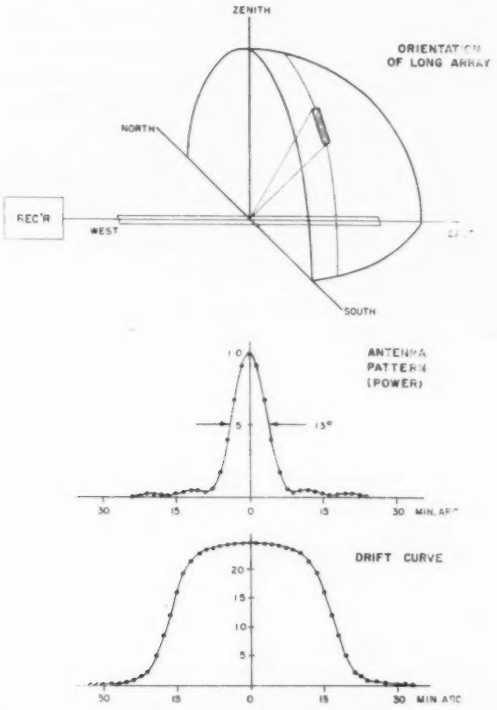

FIG. 4—Drift curve, June 30, 1954, obtained with 150-foot waveguide array: orientation of the array with antenna pattern hatched; antenna pattern in east-west direction.

between the eclipse curve and the straight line representing the total solar emission. In the absence of any precise knowledge on the variation of the radio brightness with radial distance, simple geometric criteria were used to determine the time of radio contact. A straight line was

drawn through the section of the eclipse curve near the end and was projected until it intersected the straight line representing the total emission. The point of intersection of these two lines thus determines a minimum value for the radius of the radio sun. To determine a maximum radius, the eclipse curve was hand-smoothed and the point noted at which it first deviated from the straight line representing the full value. In the model of the radio sun used to analyse the shape of the curves, the maximum radius is used to ensure that the solar field is sufficiently large to include all of the solar emission. The two values of the radius are given in Table I together with other data for the optical and radio eclipses.

TABLE I

CIRCUMSTANCES OF OPTICAL AND RADIO PARTIAL ECLIPSE OF THE SUN AT OTTAWA, CANADA, JUNE 30, 1954

		Optical	Radio
Circumstances of the Eclipse			
First contact		$10^h9^m56.8^s$	....
Middle:	*Calculated*	$11^h5^m23.9^s$	
	Observed	$11^h5^m23.5^{s*}$	$11^h5^m24^s$
Last contact		$12^h5^m36.7^s$	$12^h7^m22^s$ (earliest) $12^h9^m45^s$ (latest)
Magnitude		0.857	
Solar Radius			
Optical	15′43.9″	(1.00 $R_\odot$)	
Radio	16′41″ (min.)	(1.06 $R_\odot$)	
	18′ 0″ (max.)	(1.14 $R_\odot$)	

*Courtesy J. Locke, Dominion Observatory, Ottawa.

Analysis of Curves

The radio waves emitted from the sun induce random voltages in the antenna such that the radiation resistance of the antenna assumes an equivalent temperature T_{ant} given by the equation,

$$T_{ant} = \frac{G_0}{4\pi}\int g(\theta, \phi)\ t\ (\theta, \phi\ )d\ \Omega\,,$$

where $g(\theta, \phi)$ is the normalized receiving pattern, G_0 is the maximum antenna gain, $t(\theta, \phi)$ is the equivalent temperature in the direction (θ, ϕ), $d\ \Omega$ is an element of solid angle.

This equivalent temperature of the antenna is measured in terms of the current output of the radiometer and ultimately is given a magnitude

by reference to the known thermal radio emission from a resistor substituted for the antenna. Since both G_0 and $g(\theta, \phi)$ are known from engineering practice, the solution of the integral equation provides certain information about the radio emission as given by an equivalent temperature in various directions of space.

In applying this integral equation to analyse the results of the two experiments, certain instrumental conditions are of importance and modify the form of the equation. In the case of the eclipse curve, the broadness of the receiving pattern in comparison with the sun permits $g(\theta, \phi)$ to be set equal to one. Consequently at any given time corresponding to a given point on the eclipse curve, the magnitude of the radio emission is related to a particular sun-moon configuration, each element of area on the unobscured solar disk emitting radio waves with a certain intensity. In the case of the drift curve, the angular width of the receiving pattern in one dimension is smaller than the angular size of the solar disk so that the exact form of $g(\theta, \phi)$ in that direction must be used. Thus at any given time or point on the drift curve, the magnitude of the radio emission is proportional to the intensity of the radio waves emitted by north-south strips on the sun each weighted by the gain factor which is a function of angle in the east-west direction.

Since the unknown solar temperature distribution requires two space variables for its description, while either of the eclipse or drift curves is described in terms of a single time parameter, a solution to the modified integral equations may only be obtained after an assumption is made about the symmetry of the unknown solar temperature. This assumption effectively replaces the two unknown variables by a single variable which is now related to the single time parameter of either the eclipse or drift curve. The unknown distribution was assumed first to have circular symmetry about the centre of the disk, and separate solutions were found for both the eclipse and the drift curve. These two solutions differed from each other. This seemed unreasonable since the monitoring of the total solar emission showed that there was no change in the total emission within the five hours separating the eclipse and the drift of the sun through the long array pattern. As a further check of this incompatibility, a drift curve was constructed using the temperature distribution derived from the eclipse curve and compared with the observed drift curve; and an eclipse curve, constructed by using the temperatures derived from the drift curve, was compared with the observed eclipse curve. In both cases there was again a decided lack of agreement which was taken to indicate that the assumption of circular

symmetry was not valid. Other indications of an asymmetrical radio sun based upon work at other institutions have just recently appeared (Swarup, G. et al., 1955).

In order to remove these discrepancies, it was necessary to make a more complicated assumption about the temperature distribution on the solar disk—namely that the temperature of the equatorial regions could be different from that of the polar regions. A model with this possibility is shown in figure 5 and was used in the subsequent analysis. This geometrical model defines a region of radio emission that is circular with a radius of 18 minutes of arc and centred upon the optical sun. It is subdivided into a central disk of 12 minutes of arc radius, surrounded by four rings each 1.5 minutes of arc wide. The central disk was not subdivided since previous work with the long array had shown that this region of the sun did not contain much structure. The choice of the width of the outer rings was influenced by the fact that all previous work on the drift curves had been undertaken with such an interval. The rings are further divided into two groups: one comprising a polar region, the other an equatorial region. The radii forming the boundaries between these groups are at an angle of 38 degrees with a line parallel to the moon's path. The axis of the radio model is rotated about 3 degrees from the axis of the sun but this effect was considered of small importance in the analysis of the curves. Although this model was designed to provide for asymmetrical temperature distributions on the solar disk, it includes the symmetrical model as a special case and if the analysis of the curves had required a circularly symmetrical distribution as a solution, it still could have been obtained.

After the unknown temperature distribution was assumed to have the asymmetry depicted by the geometrical model, the drift and eclipse

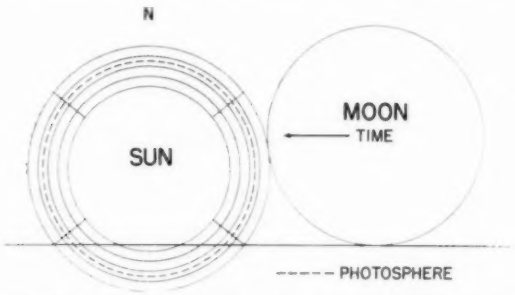

FIG. 5—Solar field used in the analysis of the curves and sun-moon configuration for the Ottawa eclipse.

curves were separately analysed in a manner that will be described subsequently. It was found that each of the original curves gave rise to temperature distributions which had an equatorial region that was brighter than the polar region. Since solutions which satisfied one of the original curves to within the expected accuracy of observation also satisfied the other independent curve to an accuracy of two or three times the expected error of observation, it was concluded that the model was satisfactory, that no significant improvement would be made by alterations such as changing the angle of the dividing line between the polar and equatorial regions, and further, that the best results could be obtained by solving the two curves simultaneously. The method of obtaining the simultaneous solution is the same as that used in examining either curve alone and will now be outlined.

A general method for the solution of an integral equation in the presence of errors involves the variation of the unknown distribution so that the observed curves may be reconstructed within the errors of observation. In the model the radio emission occurs uniformly from within the various cells and the integral equation may be replaced by a set of linear equations.

At any particular time the intensity of the radio emission as received at the antenna terminal of either the 10-foot reflector or the long array may be expressed as a sum of terms:

$$T_j = \sum^{i} a_{ij} t_i ,$$

where T_j is the reading of either the eclipse or drift curve at the time "j", t_i is the unknown temperature in the "i" cell and is the same for both the eclipse and drift curves, a_{ij} is proportional in the case of the eclipse curve to the exposed area of the "i" cell, and in the case of the drift curve to the summation of the product of the cell areas and the appropriate antenna gain. Each observed curve is thus described by an appropriate set of linear equations, each equation corresponding to a point on the curve. In the absence of any errors, any set of "i" equations would be sufficient to solve for the t_i. However, there are errors of various kinds associated with the observed curves so that incompatible solutions will be obtained from different sets of "i" equations. For example, the reading errors may be such that a set of equations based upon observations near the end of the observed curves would give a solution incompatible with that obtained from a set of equations based on observations taken at the middle of the curves. In this situation the method of least squares must be applied and a solution obtained from the normal

equations which are derived from all the original equations. Thus the original "j" equations are replaced by "i" normal equations of "i" variables and the solution of this new set is "best" in the sense that the mean square error between the observed curve and the one calculated from the solution is a minimum.

The values of temperature for the adjacent cells or rings of the model, as derived from the normal equations, often show large fluctuations. These will have no physical meaning and are certainly unreal when negative temperatures are obtained. Such solutions arise from fitting the observations with an accuracy greater than that justified by the experimental situation. In order to avoid solutions with too much detail of a fictitious nature, a modified method of analysis incorporating smoothing of the unknown temperature distribution was developed. This smoothing is introduced by adding constraints to the normal equations which confine the unknown temperature variables to polynominal forms of low degree. The direct addition of constraints through the use of undetermined multipliers proves difficult since the greater the amount of smoothing introduced, the greater are the number of constraints and the larger the determinants that enter into the solution. A more convenient method of working directly with the coefficients of the various polynominals was devised by a suitable transformation and enabled a series of solar temperature distributions of known and increasing complexity to be found. The choice of a solution is made after all the fitting errors have been computed.

The minimum fitting error for any one solution is defined as the sum of the squares of the differences between the observed readings and the readings calculated from that solution. It must be compared with the estimated error known to be associated with the equipment. The solution which has a fitting error comparable to this estimated error gives the best interpretation of the curve; those with a greater fitting error are acceptable but will be smoothed too much, while those for which the fitting error is less most likely will contain fictitious variations.

The first in the series of temperature distributions to be used in the analysis contains the least amount of detailed information in the sense that all parts of the radio disk are assumed to emit uniformly. The solution is found—in this case a constant value of temperature. A curve is reconstructed and compared with the observed curve. If the fitting error associated with this type is greater than the estimated experimental error, more information is available and another type of temperature distribution with more complexity is assumed. This second type is based upon a linear variation of temperature between the

various rings of the model. The solution is obtained and again the observed and calculated curves are compared. If there is still a significant difference between these curves, still more complexity as given by a parabolic variation between the temperature of the various rings may be introduced. When a fit comparable to the estimated error is found, this process may be discontinued since proceeding to types of greater complexity is likely to result in solutions which are influenced by accidental errors.

In the various types of temperature distribution based upon the model the successive variables introduced into the analysis allow the functional form of the temperature in the north-south direction to be independent of that for the temperatures in the east-west direction. The temperature of the central area is common to both the north-south and east-west variations.

Solutions Obtained from the Simultaneous Analysis of Eclipse and Drift Curves

The eclipse and drift curves were analysed simultaneously according to the method outlined and a series of solutions proceeding from simple to complex forms were obtained. These solutions are shown in Table II,

TABLE II

SIMULTANEOUS SOLUTIONS OF ECLIPSE AND DRIFT CURVES

Case	Type	Number of Parameters	M.S. Error (Eclipse)	M.S. Error (Drift Curve)	Temperature (degrees Kelvin)				
					r = 0′–12′	12′–13.5′NS 12′–13.5′EW	13.5′–15′NS 13.5′–15′EW	15′–16.5′NS 15′–16.5′EW	16.5′–18′NS 16.5′–18′EW
(*a*)	Uniform	1	36.78	52.16	32900	32900 32900	32900 32900	32900 32900	32900 32900
(*b*)	Uniform N–S Linear E–W	2	45.29	30.94	32100	32100 33400	32100 34600	32100 35800	32100 37100
(*c*)	Linear N–S Uniform E–W	2	10.32	46.18	35100	32500 35100	29900 35100	27200 35100	24600 35100
(*d*)	Linear N–S Linear E–W	3	14.91	31.22	34300	31800 35400	29300 36600	26700 37700	24200 38800
(*e*)	Linear N–S Parabolic E–W	4	10.92	5.05	32600	31100 50600	29500 53900	28000 42500	26400 16200
(*f*)	Parabolic N–S Linear E–W	4	7.71	15.32	37700	−2400 37000	−9200 36400	17300 35700	77100 35000
(*g*)	Parabolic N–S Parabolic E–W	5	10.03	5.08	33900	21000 48100	18000 50400	24900 40900	41800 19600
	Estimated Experimental M.S. Error		(6.7)	(8.0)					

together with the corresponding mean-square fitting errors which must be compared with the mean-square errors based on the experimental situation. The experimental error for any point on the eclipse curve is 0.5 per cent., and for the system of points involved in the analysis this percentage gives an estimated total mean-square error of 6.7. For each point on the drift curve a relative accuracy of 1.5 per cent., was estimated, giving an estimated total mean-square error for the curve of 8.0. With these values of error in mind, an examination of the table shows that solutions (e), (f) and (g) provide the best approximation to the observed results. Of these, (f) may be discarded immediately, since with its negative temperatures it has no physical meaning. The remaining two solutions, (e) and (g), have comparable errors and must be accepted. In the equatorial plane these two cases are similar in having the brightest region just inside the photospheric limb, while in the polar region, case (e) has a gradual diminution of intensity, and case (g) has a bright edge outside the photosphere which is superimposed upon a more rapid diminution. Case (e) has been taken to give the best approximation to the radio sun since it has the smaller number of parameters. A model with these temperatures represented by various shades of gray is shown in figure 6.

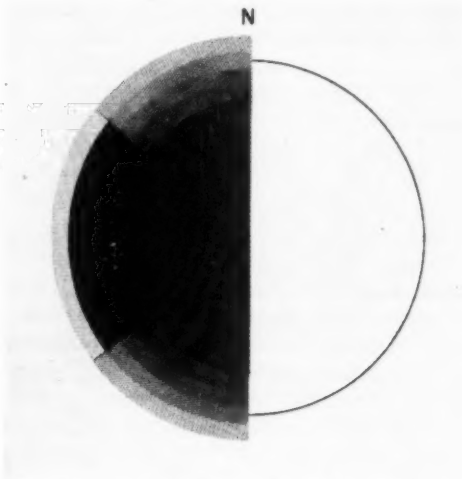

FIG. 6—Model of 10-centimetre radio sun—split along north-south axis to show relation of photosphere to temperature distribution obtained in the analysis (c.f. Table II, case (e)).

Conclusions

The early experiments in solar radio astronomy showed that radio waves originated in the direction of the sun, but gave no information on the size of the source. Calculations which were based upon an assumed emitting disk the same size as the photosphere yielded equivalent temperatures much bigger than the optical value of 6000°K., and were taken to indicate that the radio emissions were associated with the upper solar atmosphere, in particular with the solar chromosphere and the corona. These observations led Martyn to predict that solar limb brightening would be evident in the decimetre region of the spectrum. This has now been demonstrated by several observers and current problems are now shifted to the determination of the exact nature and position of the bright ring. The present work shows definitely that in the 10-centimetre region the sun is asymmetrical with pronounced bright regions on the eastern and western edges. The peak of this radiation occurs just inside the photosphere and its position should be regarded with caution since it could be very sensitive to the particular transition region between the polar and equatorial regions. In the polar regions two entirely different temperature distributions are equally satisfactory in explaining the observed curves: either a gradual darkening without a bright ring, or a more pronounced darkening with a bright edge outside the photosphere. In spite of these uncertainties, the existence of an asymmetrical sun with bright equatorial regions seems certain. This finding shows that the bright radio regions are associated with the base of the coronal equatorial streamers which were recorded at the time of this eclipse.

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Radio and Electrical Engineering Division,
National Research Council,
Ottawa, Canada.
June 1955.

VARIABLE STAR NOTES

American Association of Variable Star Observers

By MARGARET W. MAYALL, *Recorder*

Report from Dublin. (Written in Iceland, typed in Massachusetts and Ohio, printed in Canada!) Everyone who attended the meetings of the Commission dealing with variable stars at the IXth General Assembly of the International Astronomical Union came away filled with enthusiasm for future work on variables.

Much of the work of Commission 27 (Variable Stars) under the presidency of Prof. B. V. Kukarkin of the U.S.S.R., concerned the planning of future programmes with greater co-operation between observatories and visual observers in various parts of the world. Most of the astronomers present continually emphasized their need for complete light curves of the long-period, semi-regular, and irregular variables. All were in agreement that the only way they can be sure of getting these curves is through the assiduous work of the many groups of amateur observers.

The A.A.V.S.O. has been asked to add to its programme all long-period variables with maxima brighter than 11th magnitude, in addition to all U Geminorum and R Coronae variables bright enough to be observed. I have agreed to add them as rapidly as we can get charts and suitable sequences of comparison stars. This will mean extra work for all of us, but it is very necessary work. Eventually it will add several hundred stars to our programme, but we can take care of additional stars if observers will plan their observing hours more carefully.

Dr. C. Hoffmeister told of an interesting application of visual observing at his observatory at Sonneberg, Germany. Their photographic plates accumulate too much sky fog on long exposures, so all variables fainter than about 15th magnitude are observed visually, to supplement their photographic observations!

The importance of the use of photoelectric photometers was stressed for observations of rapidly varying stars and other variables with small ranges. Dr. J. L. Greenstein, President of Commission 29 (Spectra), says that visual observers have been neglecting the most important field of bright red variables with spectra of late M type and N (carbon stars). These variables have small ranges (about ½ magnitude) and

probably have periods of a year or more. They are ideally suited to a photometer on a small telescope. An accurate observation once a month should yield important results on these stars. Dr. P. Swings of Belgium recommends a long-range programme on all bright carbon stars.

Dr. Anne Underhill of the Dominion Astrophysical Observatory at Victoria, B.C., asks for more observations of shell stars. She is particularly interested in 48 Librae, which she believes may have a variation of about ½ a magnitude. It has a radial-velocity period of ± 10 years.

An informal meeting was held for a group interested in the programmes of the many variable star associations. Representatives were present from Italy, Denmark, England, Holland, France, and the U.S.A. It was agreed that the individual associations should not be limited to a particular type of variable. Each group should observe the stars best suited to its members. It was emphasized that all groups should be extremely careful to use the accepted magnitudes of comparison stars, and if any changes are needed, all groups should adopt the changes at a pre-arranged date.

Dr. George Herbig of the Lick Observatory attended the informal meeting, and made an appeal for special observations of some of the most interesting but little known variables. He would like to be notified by Air Mail of any definite sign of activity in the stars of the following groups: 1) R Coronae Borealis type such as GU Sgr and UV Cas; 2) Nova-like variables, such as AX Per and CI Cyg; and 3) some T Tauri (RW Aurigae) type variables such as RY Tau and UZ Tau. He is also very much interested in some of the early type irregular variables with large ranges, such as UX Ori, BN Ori, and WW Vul.

Prof. Kukarkin told the members of Commission 27 his plans for the new edition of the General Catalogue of Variable Stars. It is to be issued in two volumes, one the catalogue and the other references. It will thus contain much more information about the variables than the present edition, and will list references to identification charts, sequences, and so forth. We are all waiting anxiously for its publication about a year from now.

Nova Search Reports. We continue the reports using the "area-night" system. This means that each time an observer checks one region he is given credit for one Area-night of observation. The following reports are for the months of June and July, 1955. Listed first is the observer, followed by the area-nights observed in June and then the area-nights in July.

DeLorne Diedrich, 4, 2; George Diedrich, 20, 14; Paul Diedrich, 6, 7; Earl Milton, 20, 9; Wendell Perry, 0, 9; Beaufort Ragland, 24, 22; Louis Rick, 3, 24; W. H. Sullivan, 64, 101.

Observations received during July and August 1955: In July, 5,233 observations were reported by 55 observers; in August, 51 submitted 4,737, totalling 9,970 observations for the two months.

Observer	July		August		Observer	July		August	
	No. Var.	No. Ests.	No. Var.	No. Ests.		No. Var.	No. Ests.	No. Var.	No. Ests.
Adams, R. M.	57	153	57	210	Kimball, M.	6	6	6	6
Alvarez, H.	2	2	...	...	de Kock, R. P.	137	325	135	515
Ancarani, M.	21	33	23	29	Lacchini, G. B.	43	117	52	140
Anderson, C. E.	210	521	193	367	Maran, S. P.	49	65	58	119
Aronowitz, C.	109	146	87	169	Matthews, G. E.	37	48	...	...
Barber, W. F.	1	4	...	...	McPherson, C. A.	5	5	27	28
Beidler, H. B.	27	65	32	52	Melville, E. C.	11	16	7	7
Bicknell, R. H.	20	114	...	...	Michael, C. R.	11	18	...	...
Boutell, H. G.	7	17	9	41	Miller, R. H.	...	...	5	8
Breckinridge, J.	1	8	...	...	Montague, A. C.	53	75	30	47
Buckstaff, R. N.	12	20	19	50	Morgan, F. P.	6	12	...	...
Calamaras, H.	...	...	5	5	Mount, A. W.	10	10	...	...
Carlisle, J. H.	...	...	3	9	Müller, J.	18	181	...	...
Charles, D. H.	...	...	3	9	Oravec, E. G.	132	241	133	398
Cragg, T. A.	73	317	152	165	Overbeek, M. D.	72	164	...	...
Dafter, R.	...	...	5	47	Pearcy, R. E.	9	9	9	9
*Darsenius, G. O.	1	1	25	68	Peltier, L. C.	19	126	34	149
Davis, D., Jr.	4	4	...	...	Perley, Mrs. R. L.	...	...	5	5
Deemer, R.	...	...	8	8	Perry, W. L.	4	4	11	28
Diedrich, DeL.	1	2	2	2	Renner, C. J.	...	...	210	318
Diedrich, G.	5	21	8	21	Ricker, C. L.	3	4	...	...
Dorr, F.	12	63	...	...	Rizzo, P. V.	22	33	29	41
Elias, D. P.	114	435	...	...	Rosebrugh, D. W.	8	36	14	65
Fernald, C. F.	132	162	197	483	Rosenfield, D. A.	2	2	1	1
Ford, C. B.	132	140	73	75	Royer, R.	11	11	18	20
Gaustad, J. E.	...	...	17	17	Rudolph, R.	20	272	...	...
Glenn, W. H.	...	...	7	8	Schultz, G. W.	53	79	58	83
Goldenblatt, P.	36	59	53	120	Segers, C. L.	13	27	17	47
Goodsell, J. G.	...	...	4	4	Skaritka, P.	130	285	112	243
Hales, L.	5	10	6	11	Solomon, L.	79	127	43	53
Hartmann, F.	117	119	128	132	Taboada, D.	85	86	12	12
Hein, G.	78	132	86	213	Venter, S. C.	90	215	...	...
Jahn, A.	9	70	...	...	Weitzenhoffer, K.	...	...	8	14
Kelly, F. J.	12	16	11	14	Wyckoff, J.	...	...	24	52

*Also 28 minutes DO Cephei.

A.A.V.S.O. Headquarters,
4 Brattle Street,
Cambridge 38, Massachusetts,
September 1955.

NOTES FROM OBSERVATORIES

Dominion Observatory, Ottawa

On March 30th, the official opening of the Geophysical Laboratory was held in the Library-Assembly Room. An account of this function and of the new building will appear later. . . . Among those who have visited the Observatory this summer were Dr. Wm. Markowitz of the U.S. Naval Observatory and Dr. R. F. Thyer, chief Geophysicist of the Commonwealth of Australia, and the following who addressed the staff—Sir Harold Spencer Jones, Dr. R. M. Petrie, Dr. R. O. Redman, Dr. S. K. Runcorn and Dr. R. Stonely. . . . At the suggestion of Dr. Beals, a 9-hole putting course was laid out on the grounds surrounding the Observatory. The course is very popular with those who bring lunch to the office and can enjoy a half hour of recreation before returning to work . . . . The following notes cover some items of interest from the various divisions.

Positional Astronomy. The Canadian time signals, broadcast from the D.O. over station CHU, Ottawa, with a voice announcement every minute, are being received at stations as far away as New Zealand and Australia, as indicated by inquiries received from these countries. . . . Recently when comparisons were being taken between the older quartz clocks and the new ring crystal, a sudden change was noted in the comparative rates. The cause was traced to people walking in the time room. To overcome this, these crystals are being moved to a basement room and will be mounted on special shock absorbing mounts made for the Observatory by the Applied Physics Division of the National Research Council.

Stellar Physics. The Super-Schmidt meteor cameras at Meanook and Newbrook, Alberta, have resumed operation following the summer twilight period. . . . In Ottawa, plans to observe the δ Aquarid and Perseid meteor showers were largely curtailed because of poor observing weather. . . . Projects now under investigation include (1) A study of the Geminid meteor spectrum obtained at Meanook last December. (2) The mathematical theory of meteor crater formation. (3) A study of the wave-length shifts of solar spectral lines in the infra-red region. (4) A search of aerial photographs of Canada for possible meteor craters.

Geomagnetism. An airborne magnetic survey of the three Prairie Provinces by means of a three-component airborne magnetometer was

carried out during July and August. Profiles of declination, horizontal and vertical components were obtained on east-west lines sixty miles apart. . . . An installation for earth-current measurements was set up at Meanook. It will record the potential difference in two orthogonal directions between electrodes buried in the ground. . . . An astatic magnetometer for the study of remanent magnetism in rocks was designed and constructed.

Gravity. A major part of the efforts of this division during 1955 was devoted to improving the connections between the primary network of gravimeter stations, previously established. . . . An aircraft was employed for transportation, and with three gravimeters, measurements were made at most of the principal airports between Gander, Newfoundland, and Vancouver, B.C. More than 30,000 miles of flying were required to complete the project. The results should prove extremely valuable as a fundamental datum for the adjustment of all previous and future gravity surveys throughout southern Canada.

Seismology. The division acquired additional space in the D.O. recently, and an excellent laboratory has been constructed. . . . Field work has centred on the Gulf of St. Lawrence. A Navy ship, on loan from the Joint Committee on Oceanography, has dropped depth charges in the Gulf and in the Atlantic Ocean. The impulses from these charges have been recorded by seismographs set up on the Magdalen Islands, Sable Island, Prince Edward Island, and at various points on the mainland. It is hoped to determine the structure of the area, and in particular to determine the thickness of sediments in the Gulf.

The staff was augmented this summer by a number of students in addition to the following senior personnel—Dr. Luise Herzberg, Prof. J. E. Kennedy, Dr. M. S. MacPhail and Dr. S. K. Runcorn. Recent additions to the regular staff are Dr. R. L. G. Gilbert, Mr. M. Wheeler and Mr. P. Winter. J. M. Campbell, H. J. Robinson and D. C. Stockbridge have also joined the staff for duty at the northern stations of Baker Lake and Resolute Bay. Dr. Bedri Süer of the University of Ankara, Turkey, who has accepted a post-doctorate fellowship of the National Research Council, arrived to continue his studies. He is working at the Observatory on some aspects of the formation of spectral lines in stellar envelopes. . . . Mrs. Ingrid Blüme, our congenial and most capable draughtsman, resigned in August. She has returned to Sweden to rejoin her family. An informal party was held in her honour, and Dr. Beals made a presentation to her on behalf of the staff.

M. S. B.

UNIVERSITY OF NEW BRUNSWICK OBSERVATORY, FREDERICTON, N.B.

During the past winter, tests were carried out to determine the suitability of this Observatory as a permanent site for a Willmore seismograph. An account of the installation of the instrument was given in the May–June, 1955, issue of this JOURNAL.

For the trial period of operation, the seismograms were developed at U.N.B. and forwarded to the Dominion Observatory for reading. A summary of the results showed 30 earthquakes recorded between December 11, 1954, and May 18, 1955. Three of these occurred in the North Atlantic region and one at the mouth of the Saguenay River.

At certain periods, traffic on the campus and daytime use of the Observatory cause severe disturbances to the instrument, but a seismometer permanently installed within a few hundred yards of the present position, would most likely give excellent results. The registration of earthquakes in Eastern Canada would be improved appreciably by a station located at Fredericton.

The seismograph was used briefly in August when the Dominion Observatory co-operated with the Atlantic Oceanographic Group, the Nova Scotia Research Foundation and other organizations in a seismic survey of the Gulf of St. Lawrence.

J. E. K.

NOTES AND QUERIES

LARGE SUN-SPOTS

With the sun starting a new cycle of activity, the chances of observing a spectacular sun-spot group are increasing. In the June 1955 issue of the *Journal of the British Astronomical Association*, W. H. Newton discusses the Greenwich Observatory data on the twenty-five largest sun-spots occurring in the interval 1874–1954. These are tabulated in order of size. The group which heads the list occurred on April 7, 1947; its area, at maximum, was 6132 millionths of the area of the sun's visible hemisphere, and is by far the largest in the eighty years of the Greenwich records.

Naked-eye spots were recorded long before the invention of the telescope, but they were thought to be caused by the passage of Mercury across the face of the sun. The idea of such blemishes as dark, changing, spots on the sun was distasteful to the supporters of the old views,

according to which celestial bodies were perfect and unchangeable. It was left to Galileo to prove, in 1612, that the spots must be on the surface of the sun.

If the eyes are suitably screened from the glare of the sun, spots of area 500 millionths of the sun's hemisphere can be seen when near the centre of the disk. The spot of April 1947 appears to be unsurpassed in size in all the history of sun-spot observations. The last item in the list of the twenty-five largest sun-spots is a group with an area about 2000 millionths of the sun's visible hemisphere. These groups extend over an area of from 100,000 to 180,000 miles in length and from 50,000 to 75,000 miles in width.

The duration of these great groups is not longer in proportion to their size. In general, the maximum area of a large group will be reached in about eight or nine days from its origin; as it declines half the maximum area is reached on the 22nd day after origin, or about two weeks after maximum growth. The longest-lived spot group occurred in 1948 from May 26 to November 11, an interval of 170 days. In this case there is little uncertainty about the continuity of the spot. This is in contrast to a group in 1840–41, which was claimed to have lasted for eighteen months. It has been shown that there were breaks in the continuity of this group, with six or seven distinct revivals.

When frequency curves for the great sun-spots are compared with the general sun-spot curve, they agree quite closely. However, there is a tendency for the peak maximum of the great spots to occur a little before sun-spot maximum. The latitudes of the great spots range from over 31° to 5°, following the cyclical progression from high to low latitudes as the sun-spot cycle advances. Thus, at the present time, at the beginning of a new cycle, the spots appear at high latitudes.

R. J. N.

The Age of Meteorites

The geological ages of meteorites are of interest in themselves; also, they may give a clue to their origin. One method used by geochemists to derive the ages of meteorites and of many rocks consists of carefully measuring their contents of radio-active elements (uranium and thorium) and of helium. Radio-active elements disintegrate at a uniform and measurable rate, producing electrons, hard X-rays and helium atoms. Once the quantities of helium and the radio-active elements are measured in a sample, the known rate of production of helium gives a measure of its age. For stoney meteorites this method is being supplemented by one involving the measurement of the amounts of argon and potas-

sium. It is of interest to determine whether the two methods give the same age for identical samples. Reasbeck and Mayne recently reported on an investigation of this kind (*Nature*, July 30, 1955). They found that the two methods appear to be in substantial agreement, and yield an age for stoney-phase meteorites of from 2 to 4 $\times$ 10^9 years. Thus these meteorites are of about the same age as the earth. On the other hand, these workers found the iron-phase meteorites to be younger, and to have an age of 2 or 3 $\times$ 10^8 years.

It has been argued that ages based on helium measurements may be too low, because helium might escape. Reasbeck and Mayne, from a number of experimental observations, have been led to the conclusion that this effect may not be really serious.

The authors point out that the older age of the stoney meteorites compared with the irons makes the hypothesis of a planetary origin for all meteorites very attractive. In the development of a planet the heavy material is thought to have collected at the centre, and the solidification to have started at the outside and worked in to the core. Thus the outer (stoney) region would be older than the more-recently solidified (iron) core. If such a planet broke up shortly after the solidification of most of the iron phase, the outer portions could have formed stoney meteorites (old); the inner core could have formed iron meteorites (younger); the intermediate part could have formed chrondites, passasites, etc., which combine features of the stoney and iron phases. Some further corroboration of this theory comes from the metallurgical investigations of iron meteorites by Uhlig, which seem to indicate that the irons were formed in the interior of a large body. It is a fascinating theory.

R. J. N.

Canadians at the I.A.U. in Dublin

The Ninth General Assembly of the International Astronomical Union was held in Dublin, Eire, from August 29 to September 5. With fine weather, the kindest hospitality, and interesting reports of astronomical work done and planned, the meetings were immensely successful. A report of the congress will appear in the next issue of the Journal.

Canada was well represented. From the Dominion Astrophysical Observatory: Andrew McKellar, official head of the delegation, Anne B. Underhill, K. O. Wright; from the University of Western Ontario: R. W. Nichols; from the David Dunlap Observatory: John F. Heard, Helen S. Hogg, Donald A. MacRae, Ruth J. Northcott, J. B. Oke; from Queen's University: A. Vibert Douglas; from Saint Mary's University: M. W. Burke-Gaffney.

REVIEW OF PUBLICATIONS

The Earth as a Planet edited by Gerard P. Kuiper. Pages xvii plus 751; 7 x 9¾ in. Chicago, The University of Chicago Press (in Canada, The University of Toronto Press), 1954. Price $12.50.

This book is the second in a series of four volumes on the Solar System edited by Prof. Gerard P. Kuiper of the Yerkes Observatory. The first was "The Sun", reviewed in this JOURNAL for Jan.–Feb. 1955. Like the earlier volume, "The Earth as a Planet" is designed to be "both a reference book for the specialist and a source of general information for the reader having some acquaintance with the physical sciences". For such a book about the earth there has long been a great need. Gamow's "Biography of the Earth" is an entertaining popular treatment, whereas Jeffrey's "The Earth" is a difficult analytical account of selected topics. The present work falls between the two in style and greatly exceeds both in scope.

It is the first six chapters, occupying rather less than half the book, which particularly fill the need referred to above. These chapters are as follows: The Dimensions and Rotation of the Earth by Sir Harold Spencer Jones, the Dynamics of the Earth-Moon system by Sir Harold Jeffries, The Interior of the Earth by Sir Edward Bullard, The Development and Structure of the Crust by J. Tuzo Wilson of the University of Toronto, Oceanography by H. U. Sverdrup of Oslo, and The Geochemistry of the Crust by Brian Mason of the American Museum of Natural History.

The subject matter of the last nine chapters, dealing with the earth's atmosphere, largely overlaps that of "The Atmospheres of the Earth and Planets", also edited by Prof. Kuiper, a revised edition of which appeared in 1952 (this JOURNAL, vol. 47, p. 122, 1953). One can understand the desire of the Editor to include this subject matter in the present book for the sake of completeness; otherwise there would have been little reason for its duplication.

As the title suggests the book has a distinct astronomical flavour. One cannot help but be impressed by the extent to which astronomical observations have contributed to our knowledge of the earth. At the same time, and more especially in recent years, the increasing knowledge of the earth is contributing abundantly to our understanding of the

other members of the solar system. The reader may be surprised to learn in the chapters by Spencer Jones and Jeffreys how much information concerning the earth's interior has been wrung from telescopic observations of the stars; he may be equally surprised to learn in the chapter on oceanography how the study of the ocean floor is now giving the best direct information on micrometeorites. The astronomical reader will probably find the most fascinating reading in the chapter entitled "The Biochemistry of the Terrestrial Atmosphere" by B. E. Hutchinson of Yale University. This contribution traces carefully the various chemical processes that can be expected to have affected the chemistry of the earth throughout its history, including the role played by plant and animal life. It is from this point that discussion of possible life on other planets can most profitably begin.

Prof. Kuiper has an excellent faculty for maintaining good uniformity and continuity among the contributed chapters. There is nowhere so much difficult mathematics but what the general reader may follow the development without much trouble. For the more scientific reader there is sufficient analytical detail for a good working understanding, and to fill in the gaps there are excellent reference lists with each chapter. As well as a subject index there is a very useful index of definitions. Among the illustrations the outstanding ones are the eight magnificent photographs of the south-western United States taken from rockets at heights of about 75 miles.

"The Earth as a Planet" belongs in any scientific library—astronomical, physical, chemical, geological, biological. It belongs in any library, in fact; it is the natural history of the earth.

J. F. H.

MEETINGS OF THE SOCIETY

AT EDMONTON

June 30, 1954—Eclipse of the sun, June 30, 1954, as observed by the Edmonton Centre.

Observers: Ian McLennan, Arthur Dalton, Marcel Dalton, Earl Milton, Mr. Montgomery, Mr. Wilson and sons, Franklin Loehde as well as a number of employees of the MacDonald Hotel.

Location: On the fourteenth-story roof of the MacDonald Hotel.

Weather Conditions: Very clear except for the occasional high cloud.

Equipment: A 6-inch reflector, 3 binoculars, 1½-inch refractor, an 8 mm. movie camera (colour) and three other cameras.

Observations: The sun rose at 4:04 a.m. Mountain Standard Time with the moon covering about 30 per cent. of the sun's disk. Because of the sun being near the horizon the disk was rather elongated. A number 10 welder's glass was used to take a number of photographs through the telescope at $\frac{1}{50}$ sec. Colour movies were taken of most phases of the eclipse including sunrise. The photographs and the movies showed that about 65 per cent. of the sum was eclipsed at maximum which was at 4:29 a.m. By 5:16 a.m. the eclipse was over. Lack of a short-wave radio prevented accurate timing of the last contact.

E. H. Gowan, *Secretary*.

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